Synergistic effects of vegetation layers of maize and potato intercropping on soil erosion on sloping land in Yunnan Province, China

Abstract: Intercropping, as an overyielding system, can decrease soil erosion on sloping land through the presence of dense canopy covers. However, the structure mechanism in canopy is still unclear. We conducted a two-year field experiment on runoff plots, exploring whether the interaction between vegetation layers reduce soil erosion in maize and potato intercropping systems. The maize, potato, and weed layers in the intercropping system were removed by a single layer, two layers and three layers, respectively (total of 8 treatments including all layers removed as the control). Then, throughfall, runoff and sediment were measured at the plot and row scale on a weekly basis. Based on the difference between each treatment and the control, we calculated and found a relative reduction of runoff and sediment by any combination of the two vegetation layers greater than the sum of each single layer. In 2016 and 2017, the highest relative reduction of runoff reached 15.65 and 46.73%, respectively. Sediment loss decreased by 33.96 and 42.77%, respectively. Moreover, runoff and sediment reduced by the combination of all vegetation layers (no layers removed) was also larger than the sum of that by each single layer. In 2016 and 2017, the highest relative reduction of runoff reached 7.32 and 3.48%, respectively. So, there were synergistic effects among multi-level (two or three layers) vegetation layers in terms of decreasing soil erosion on sloping land. Maize redistributes more throughfall at the maize intra-specific row and the maize and potato inter-specific, which is favourable for the synergistic effect of reducing soil erosion. This finding shows an important mechanism of maize and potato intercropping for soil and water conservation, and may promote the application of diverse cropping systems for sustainable agriculture in mountainous areas.

Keywords: synergistic effect; vegetation layer; soil erosion; intercropping; maize; potato

Introduction

Soil is very importance in the earth system (Keesstra et al. 2016). However, soil loss due to erosion is one of the major environmental problems facing the world today (Zhu et al. 2015; Poesen 2018), which pose great challenges to socio-economic sustainable development (Smith et al. 2016; Yang and Lu, 2017). The soil erosion occur mainly in mountain area, and largely driven by cultivation on sloping land (Gessesse et al. 2015). The soil loss from tillage erosion was ≤151 Mg ha^{-1} $year^{-1}$ (Zhang et al. 2004). Therefore, the strategies are need to reduce soil erosion on sloping land (Keesstra et al. 2018a). Recently, many agricultural technologies have been adopted, these technologies include terraced fields (Chen et al. 2012), hedgerow technology (Xing et al. 2017), no-tillage (Mhazo et al. 2016), minimum tillage (Ngetich et al. 2014), mulch (Vega et al. 2014; Cerdà et al. 2018a), and crop diversity (Laloy and Bielders, 2010; Sharma et al. 2017; Cerdà et al. 2018b). Among these technologies, crop diversity can also enhance the use of nutrients, water and light, and reduce yield and quality losses due to pests and diseases. Therefore, as an important sustainable agricultural technology, crop diversity has accepted for reducing soil erosion globally (Nelson and Cramb, 1998; Ouyang et al. 2017).

Intercropping is an important crop diversity technique. It has been confirmed that intercropping reduces soil erosion on sloping land in many parts of the world, including China (Barton et al. 2004), India (Kurothe et al. 2015), Belgium (Laloy and Bielders, 2010) and Africa (Laurenson et al. 2013; Ndiritu et al. 2014). Moreover, the soil conservation effect of intercropping on soil erosion is superior than monoculture. For example, Yang (2011) found that the maximum runoff and sediment loss from maize intercropping with potato and cabbage is 55.3 and 85.3%, respectively, less than from maize monoculture. Compared with monoculture, intercropping can reduce soil erosion through many processes. From above-ground, studies show that intercropping can increase canopy coverage (Duchini et al. 2016), which may reduces throughfall impact on the soil surface, and slows overland flow velocity, and this process may be the main reason why intercropping can decrease soil erosion by adjusting the canopy. However, research is limited regarding the role of canopy cover (Zhou et al. 2008; Butt et al. 2010), and little attention has focused on the stratified vegetation cover of intercropping systems, and relationships between the different canopy layers.

Communities composed of different plants often have specific hierarchical structures, which plays important roles in determining the functions of their communities (Bello et al. 2013). For example, the leaves from different vegetation layers can provide diverse habitats for animals (Barsoum et al. 2016). Moreover, the leaves with different surface conditions have special hydrological functions (Wang and Duan, 2010). Besides, the canopy of plants are different in recovery reaction from stress (Zenner et al. 2013). These vegetation functions will change when the composition of vegetation vary. Pretzsch (2014) studied the canopy function of mixed forest, finding that there is a "*real mixing effect*" between vegetation layers with different sizes, shapes and relative locations. Therefore, exploring the specific interactions among different vegetation components is very important (Kembel, 2006; Forrester, 2014). However, whether there were coupling interactions between vegetation layers in reducing soil erosion, especially in intercropping systems, remains an important question.

Maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) intercropping is an important multi-cropping system, which has been adopted in many parts of the world, and has been proved to have significant yield advantages (Batugal et al. 1990; Wu et al. 2014). Moreover, this cropping system can greatly reduce soil erosion on sloping land (Fan et al. 2016), and is widely adopted in mountainous areas. Therefore, our study explored whether the reduced soil erosion from maize and potato intercropping came from the synergistic effects between vegetation layers. To do this, we conducted a two-year field experiment on runoff plots. The maize, potato and weed layers were removed by a single layer, two layers and three layers, respectively. Then, we measured throughfall, runoff and sediment in both intra-specific and inter-specific rows, and evaluated the role of each canopy on soil erosion. Our hypotheses are that: (1) vegetation layers are functionally varied in the effect on soil erosion, and (2) in maize and potato intercropping systems, there is a coupling effect among vegetation layers which decreases soil erosion on sloping land.

1. Materials and methods

1.1 Study location

The experimental site is located in Shilin County, Kunming City, Yunnan Province, south-west China (24°52′05″N, 103°27′25″E, 1942.5 m above sea-level). The sun-shine hours and frost-free period per year at the study location are 2339.0 h and 252 days, respectively. The accumulated temperature (≥10°C) is 4814.6°C. Mean annual rainfall is 949.6 mm, and the rainy season is from May-October, accounting for 88% of annual rainfall. The soil of the experimental site is Red soil (Chinese classification) with pH value of 5.78, and a soil organic matter content of 21.6 g kg^{-1}. The total nitrogen (N), total phosphorus (P) and total potassium (K) contents were 1.14 g kg^{-1}, 0.69 g kg^{-1} and 17.80 g kg^{-1}, respectively. Accordingly, the hydrolytic N, available P and available K were 118.1 mg kg^{-1}, 44.9 mg kg^{-1} and 104 mg kg^{-1}, respectively.

1.2 Experimental design

The experiment was conducted on a micro-runoff plot in 2016 and 2017. The plot slope is 8° with an area of 4.32 m^2 (length 3.6 m × wide 1.2 m) (Fig. 1). In this experiment, the variety of maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) were Yunrui 88 and Yunshu 801, respectively. The Yunshu 801 is a variety with high tolerance to late blight and is shade tolerant, while Yunrui-88 is a high yield variety in Yunnan Province. Therefore, the cultivar combination is widely used in the experimental area. Based on the intercropping system, we removed the maize, potato and weed vegetation layers (16 July 2016, and 22 July 2017) by a single layer, two layers and three layers, respectively. Consequently, there were eight treatments including no layer removed (IC), weed layer removed (WR), potato layer removed (PR), maize layer removed (MR), both weed and potato layers removed (WPR), both weed and maize layers removed (WMR), both potato and maize layers removed (PMR), and weed, potato and maize layers all removed as the control. Each treatment was replicated three times and arranged within three randomly chosen blocks. Operationally, we cut plants at stem bases and removed maize and potato layer using branch shears. To avoid damage to the surface soil, the weed layer was carefully cut near the ground (0.5-1 cm above-ground) using scissors.

Two crops were grown along the contour line with 2:2 row ratio. The spacing of both intra-specific and inter-specific rows were 40 cm. The plant spacing of maize and potato were 20 and 30 cm, respectively. Therefore, the planting density of maize and potato were 62,503 plants ha^{-1} and 41,669 plants ha^{-1}, respectively. Before sowing, the potato tuber was selected as seed if it was healthy, regular, smooth, bright and moderate size (weight ～ 50 g). Potatoes were sown on 2 April 2016, and 26 March 2017, respectively, and harvested on 20 August 2016, and 18 August 2017, respectively. The maize was planted by transplanting seedlings. In 2016, the transplanting and harvest date were on 14 May and 12 October, respectively. In 2017, the transplanting and harvest date of maize were on 16 May and 10 October, respectively.

Both maize and potato were treated with refined organic fertilizer (organic matter ≥45%, $N+P_2O_5+K_2O$ ≥5%, 15,000 kg ha^{-1}) and compound fertilizer ($N-P_2O_5-K_2O$: 15-15-15, 600 kg ha^{-1}) as base fertilizer. In addition, urea (total nitrogen ≥46.4%) was applied to maize at the seventh leaf stage (jointing stage) and 12 leaf stage (bell stage) at 150 and 300 kg ha^{-1}, respectively. At the seedling stage of crops (30 days after sowing), the field maximum water-holding capacity was kept at 60-70% by regular watering. At the same time, necessary pest and disease control was conducted.

1.3 Measurements

1.3.1 Rainfall

A small automatic weather station (AWS; PG-210/YL, Hebei Pinggao Electronic Technology Co., Ltd.) was placed in an open area 50 m from the plot. During the experiment period, the AWS recorded rainfall (precision: 0.2 mm) every 30 min.

1.3.2 Runoff and sediment of runoff plots

Runoff

A plastic bucket was used to collect runoff from the micro-runoff plots, and the volume of bucket (V) was calculated using the equation:

$$V = \frac{1}{3}\pi h(r^2 + R^2 + rR) = \frac{1}{3} \times \pi h[r^2 + (r + h\ \tan\alpha)^2 + r(r + h\ \tan\alpha)] \quad (1)$$

Where r was the bottom radius, R was the upper bottom radius, and H was the height of the plastic bucket. Then, the height of runoff in the plastic bucket was measured with a ruler (precision: 0.1 cm) at 1200 (if rainfall had occurred). Finally, plot runoff (V_1, unit: m^3 hm^{-2}) was calculated according to the height (h, unit: cm) of runoff in the plastic bucket, using the equation:

$$V_1 = [\frac{1}{3}\pi h(r^2 + R^2 + rR)] \div (100 \times 4.32) = \{\frac{1}{3}\pi h[r^2 + (r + h\tan\alpha)^2 + r(r + h\tan\alpha)]\} \div (100 \times 4.32)$$
$$V_1 = (854.865h + 5.397h^2 + 0.545h^3) \div (100 \times 4.32) \quad (2)$$

Sediment

After measuring runoff, runoff in the plastic bucket was fully stirred. Then a 200 mL sample was removed from the top, middle and lower layers, and filtered in the laboratory with a filter paper (diameter 12.50 cm, mass 1.50 g). After filtering, the filter paper was oven-dried at 105°C to constant weight. The sediment yield of sample m_1 was recorded and the sediment (M_1, unit: kg ha^{-1}) was calculated by combining with the plot runoff (V_1, unit: m^3 hm^{-2}) data.

$$M_1 = \frac{(m_1 - 1.50) \times V_1}{200} \times 10^3 \quad (3)$$

1.3.3 Runoff, sediment and throughfall in the intra- and inter-specific rows

Runoff in the intra- and inter-specific rows

We designed a device to study the distribution of throughfall, runoff and soil erosion in different rows (Fig. 2), The device can synchronously measure throughfall, runoff and sediment in the intra- and inter-specific rows. Three devices were placed in each plot. As a result, a total of 72 devices were installed. Practically, the surface undisturbed soil (10.0 cm) in the runoff plot was added to the erosion trough (39.5 cm × 26.5 cm × 15.0 cm) of the devices before sowing. Then, the erosion trough was installed in the maize intra-specific row, maize and potato inter-specific row and potato intra-specific row. The slope of the erosion trough was adjusted to be consistent with the plot. When the vegetation layers were removed, the runoff and percolation water in different rows were collected by their respective devices. Then the volume was measured with a graduated cylinder (v, unit: cm^3). The method of obtaining the sampled sediment (m_2, unit: g) was similar to that of m_1. Finally, runoff (V_2, unit: m^3 hm^{-2}) and sediment (M_2, unit: kg hm^{-2}) in the intra- and inter-specific rows were obtained by the same methods used on the whole plot.

$$V_2 = \frac{v}{39.5 \times 26.5} \times 10^2 \tag{4}$$

$$M_2 = \frac{(m_2 - 1.50) \times V_2 \times 10^6}{200} \times 10^{-3} \tag{5}$$

The distribution of throughfall (V_{Thr}, unit: m^3 hm^{-2}) in the intra- and inter-specific rows was determined using the formula:

$$V_{Thr} = V_2 + V_{per} + \Delta V_{Soil} \tag{6}$$

$$\Delta V_{Soil} = \Delta C \times 10^4 = (C_{After} - C_{Before}) \times 10^4 \tag{7}$$

Where V_2 (unit: m^3 hm^{-2}) is the runoff in the intra- and inter-specific rows; V_{per} (unit: m^3 hm^{-2}) is the percolation water; □V_{soil} (unit: m^3 hm^{-2}) is the change of soil water content after rainfall (soil water storage); C_{Before} (unit: %) and C_{After} (unit: %) were soil moisture content before and after rainfall. A TDR100 soil moisture meter (SPECTRUM, USA) was used to measure soil moisture content at 7.6 cm soil depth.

1.4 Data analysis

SPSS Statistics 23.0 was used for statistical analysis. The variance of runoff and sediment in plots was analysed by two-way ANOVA with the different removal styles of vegetation layer and block as fixed factors. The variance of precipitation, runoff and sediment at different rows was analysed using two-way ANOVA with maize and potato inter- and intra-specific rows as fixed factors. Multiple comparisons of means were performed using Duncan test at $P \leq 0.05$. Data were log10-transformed, if necessary, to reduce the heterogeneity of variances, and homogeneity was tested using Levene' s test.

2. Results

2.1 Rainfall characteristics

After vegetation layers were removed, the rainfall data were obtained within ≤7 days. After 16 July 2016, there were two rainfall events (rainfall intensity 12.2 mm $24h^{-1}$ and 21.2 mm $24h^{-1}$ on 18 and 19 July, respectively), with a total of 33.4 mm of rainfall. After 22 July 2017, there were four rainfall events (24 h rainfall intensity 5.6 mm, 11.4 mm, 9.2 mm and 20.2 mm on 23, 24, 26 and 27 July, respectively), with a total rainfall of 46.4 mm.

2.2 Runoff and sediment in plots

Compared to the control, the addition of vegetation layer on the bare soil significantly decreased runoff, especially when the number of vegetation layers was more than one (Fig. 3). However, the effect of adding one vegetation layer to two vegetation layers depended on vegetation type. Adding potato or maize layers significantly decreased runoff, while adding the weed layer did not significantly decrease runoff, indicating that the weed layer had least effect on runoff. Furthermore, comparing runoff between PR and WMR treatments, we found that the potato layer made the most contribution to decreased runoff (Fig. 3). The runoff reduced by the single potato layer was greater than the sum of that reduced by the single maize layer and the weed layer. Runoff reduction by single maize was significantly higher than that of weeds in 2017, but there was no significant difference in 2016.

There was a synergistic effect on reduced runoff between vegetation layers. In 2016 and 2017, total runoff reduction from the two layer vegetation combination was larger than the sum of runoff reduction of single layer vegetation. Runoff decreased by 5.83-10.02 m^3 ha^{-1} and 19.36-23.82 m^3 ha^{-1}, respectively, and the reduced rates were 5.97-15.65% and 11.47-33.96%, respectively (Tab. 1). Among them, the largest synergistic effects were the maize and potato combinations, while the largest decrease was in the weed and maize combinations. Similarly, the synergistic effect also existed in the three layers of vegetation (IC treatment). The synergistic effects of runoff in 2016 and 2017 were 2.24 m^3 ha^{-1} and 16.29 m^3 ha^{-1}, respectively, and the runoff decrease was 1.79-7.32% (Tab. 1).

The effect of vegetation stratification and its combined coverage on sediment loss from intercropping followed the same pattern as runoff. In single layer removal treatment, sediment from the PR treatment was significantly higher than that of the MR and WR treatments, while the sediment from WMR in two-layer removal treatments was significantly lower than that in the WPR and PMR treatments (Fig. 4). Therefore, the reducing effect of the potato layer on sediment was greatest. Similarly, sediment loss from the WMR treatment was significantly less than from the PR treatment, which indicated that the reducing effect of the potato layer on sediment was greater than the sum of the weed and maize layers. The reduced sediment loss in two-layer combinations (except PR treatment) and three-layer combination (IC treatments) were larger than the total amount of reduced sediment by each single layer (WPR, WMR and PMR treatments) (Fig. 4). The results showed that the multi-layers structure of maize and potato intercropping systems strengthened the effect of vegetation cover on decreasing sediment loss. At the same time, when the number of layers increased from two layers to three layers, the change of sediment was also affected by vegetation type. Among them, the increase of potato significantly reduced sediment loss, while the effect of increased weed cover was not significant. When maize was added, the difference was not significant in 2016, but was significant in 2017. That is, there was no significant difference in terms of decreased sediment loss between maize and weeds in 2016, but the maize effect was significantly higher than that of weeds in 2017.

The synergistic effect of multi-level (two or three layers) vegetation combinations also evident for sediment loss. In 2016 and 2017, total sediment reduction in the two-layer vegetation combinations were larger than the sum of sediment reduction in single layer vegetation. Sediment loss decreased by 20.98-45.56 kg ha^{-1} and 42.58-62.38 kg ha^{-1}, equivalent to rates of 7.23-46.73% and 8.28-42.77%, (Tab. 2). Among them, the synergistic effect of maize and potato combinations was the largest in 2016, while weed and maize combinations were the largest in 2017. Similarly, the decreased sediment loss from the IC treatment exceeded the sum of each single layer in both 2016 and 2017. The relative reductions were 9.60 kg ha^{-1} and 19.08 kg ha^{-1}, respectively, equivalent to rates of 2.90-3.48% (Tab. 2).

2.3 Throughfall distribution in the intra- and inter-specific rows

There were significant differences in throughfall among intra- and inter-specific rows. When no vegetation layer was removed (IC), throughfall was most in the potato intra-specific rows. Conversely, throughfall was least in the maize intra-specific rows. When the weed or potato layer was removed but the maize layer remained (WR, PR and WPR treatments), throughfall distribution was similar to that in IC, suggesting that maize played key roles in throughfall redistribution. However, when we removed the maize vegetation layer (MR, WMR and PMR treatments), the difference in throughfall among intra- and inter-specific rows were small and not significant (except in 2016). Moreover, throughfall in the inter-specific row under maize (IC, WR, PR and WPR treatments) were significantly higher than that under the maize removal treatment (Tab. 3). Thus, intercropped maize can redistribute more throughfall in inter-specific rows.

2.4 Runoff and sediment loss in the intra- and inter-specific rows

There were significant differences in runoff among intra- and inter-specific rows of maize removal treatments (MR, WMR, PMR and CK).The greatest difference was in the maize intra-specific row, the second greatest difference was in the maize and potato inter-specific row, and the least difference was in the potato intra-specific row. After removal of potato (PR, WPR; not including PMR treatment), runoff from potato intra-specific rows was significantly higher than that from the maize and potato inter-specific rows and the maize intra-specific rows, but the difference between the latter two were not significant (Tab. 4). Thus, maize significantly affected runoff from maize intra-specific rows, while potato significantly affected runoff in maize and potato inter-specific rows and potato intra-specific rows. When the maize and potato inter-specific rows were covered with maize and potato (IC and WR), runoff from the maize and potato inter-specific rows were least (except WR, 2016). Among them, the difference was significant in 2017 (Tab. 4).

Sediment yields from intra- and inter-specific rows in intercropping systems were similar to runoff trends. After maize removal (WMR, PMR and CK), there were significant differences in sediment loss from the intra- and inter-specific rows, which showed that most sediment loss was from the maize intra-specific row, the second was from the maize and potato inter-specific row, and the least was from the potato intra-specific row (Tab. 5). When the potato layer was removed, the different rows had different patterns of sediment loss. Among them, when potato and maize were removed simultaneously (PMR), sediment loss was the same as that from the other maize removal treatments. However, when only potato was removed (PR), most sediment loss was from the potato intra-specific rows, and the least was from maize intra-specific rows in 2016. In contrast, in 2017, sediment loss was least from the potato intra-specific row, and most was from the maize intra-specific row. When the maize and potato were both present (IC and WR), sediment loss from the maize and potato inter-specific rows was significantly lower than from the potato intra-specific rows. When potato and weed were both removed (WPR), sediment loss was similar to that from IC and WR treatments (Tab. 5). The difference was that there was no significant difference in sediment loss from the maize and potato inter-specific rows and the potato intra-specific rows in 2016.

3. Discussion

Our two-year study found that there were synergistic effects of vegetation layers within diverse cropping systems and decreased soil erosion rates. Compared with total runoff reduction from each single vegetation layer, runoff reduction from the combination of potato and maize significantly decreased by 10.02 and 23.82 m^3 ha^{-1}, respectively. Therefore, more vegetation layers present greater potential for synergistic effects to decrease soil erosion. The reduction of sediment loss by the combination of maize, potato and weed (IC) was 9.60 kg ha^{-1} (2016) and 19.08 kg ha^{-1} (2017); larger than that by each vegetation layer singly. Monoculture is still the main planting pattern in Yunnan(Yang et al. 2017), which leads to simple vegetation layer structures, and could be an important reason for increased soil erosion on sloping land. So the synergistic relationships between different crop vegetation layers merit attention (Kateb et al. 2013).

Potatoes had most effect on soil and water conservation. The soil and water conservation effects of potatoes were larger than the sum of maize and weeds. Adding a potato vegetation layer plays an important role in soil and water conservation in intercropping systems. The reason is that potato is a dicotyledonous, cluster and dwarf crop, which can completely cover soil surfaces (Sojka et al. 1991; Guo 2000). Therefore, choosing suitable species in intercropping systems is an important design consideration in soil and water conservation systems. Functional groups have greater importance than species diversity in decreasing soil erosion in the natural ecological environment (Berendse et al. 2015; Hou et al. 2016). Although soil erosion decrease by the potato layer was larger than that by both maize and weed layers, the potential of maize and weed layers still deserve attention. Firstly, many studies have confirmed that the soil erosion decreases effect of intercropping is greater than that of any monoculture(Wall et al. 1991; Zougmore et al. 2000; Laloy and Bielders, 2010). Secondly, this study found that there were synergistic effects among different vegetation layers, which cannot occur without the disadvantage crop decreasing soil erosion. This indicates that the advantage crop reducing soil erosion has greater potential when intercropped with a disadvantage crop.

Why was there synergistic effect in the intercropping system for reducing soil erosion? An important reason is the throughfall redistribution driven by the plant systems. Our data showed that the highest, medium and least throughfall distribution was in the intra-specific (potato) row, inter-specific row and intra-specific (maize) row, respectively. For maize, the leaves at intra-specific row grow upwards due to light competition(Ma et al. 2018).The leaves of inter-specific rows tended to grow laterally. This leaf-structure morphology redistributes throughfall. Throughfall on maize intra-specific rows is more likely be directed to the ground as stem-flow (Zheng et al. 2017), while that on inter-specific rows is more likely to flow along the extension and lateral leaves. For potatoes in the mid to late growth stages, growth is mainly lateral. Therefore, stem-flow on potatoes may be less(Jefferies and Mackerron, 1985), resulting in the larger redistribution of throughfall within the potato intra-specific row.

Soil erosion in the intra- and inter-specific rows was different from the throughfall distribution. When we removed all vegetation layers, the highest, medium and lowest soil erosion was in the maize intra-specific row, inter-specific row and potato intra-specific row, respectively. This soil erosion distribution may be related (Keesstra et al. 2018b) to difference in infiltration rates and soil conservation performance between maize and potatoes. However, under the no vegetation layer removed condition, the highest, medium and lowest soil erosion was found in the maize intra-specific row, potato intra-specific row and inter-specific row, respectively. The reason may be that there are three vertical vegetation layers at the maize and potato inter-specific row, which is beneficial for the synergistic effect. Maize is the highest vegetation layer, and thus is the first layer to intercept raindrops, and absorb their kinetic energy. Then potato and weeds vegetation layer is the second 'defence line,' which further intercept raindrops, further decreasing their kinetic energy. Simultaneously, maize redistributes more throughfall in inter-specific rows, which pose greater potential for the synergistic effects among the three vegetation layers.

Chemical herbicides are widely used to remove weeds in conventional farming(Huang et al. 2016), but the overused application of herbicide lead to serious environmental risks (Lapworth et al. 2012; Guijarro et al. 2018). This study reserved the weed layer, and studied its influence on soil and water conservation in intercropping systems. Our data showed that the weed layer promoted synergistic effects between vegetation layers. At the same time, weed layer increase the soil surface roughness which can reduce the soil erosion (Zhao et al, 2018). Therefore, it is recommended that weeds should be moderately controlled to integrate crop yield and ecological benefits. In the experimental area, due to strong competition from weeds, weed control was carried out at the early stage of crop growth. However, in the middle and late stages of crop growth, the rainfall is concentrated (i.e. the rainfall duration and intensity are very high) and the weeds had relatively little effect on crop yield and quality. Hence, the weed layer can continue to play its role in soil and water conservation. The hydro-erosional effects of weed cover merit further investigation.

4. Conclusions

In maize and potato intercropping systems, the soil conservation effects of vegetation layers vary. The potato vegetation layer has most effect on soil and water conservation, greater than the sum of that from maize and weeds. There are synergistic effects from multi-level (two or three layers) vegetation layers in terms of decreasing soil erosion rates on sloping land. Maize redistributes throughfall in the maize intra-specific row, and the maize and potato inter-specific rows, which promote the synergistic effect of decreased soil erosion.

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